DC BIASING FOR BJT's[1]

TRANSISTOR BIASING

Proper biasing of the transistor means everything. A transistor amplifier cannot function properly if it is not biased properly. But what does it mean to bias a transistor'? The word bias means to offset or to establish preset conditions. A transistor must be set up in a circuit that is designed to provide the offset voltage(s) for the desired preset conditions. In this way, base and collector currents are established as idling **currents,** most often called **quiescent currents** (static currents). These quiescent currents then establish **quiescent voltages** across the transistor and associated resistors. Here, you begin your exploration of biasing schemes with the simplest of biasing techniques, called base bias.

BASE-BIAS ANALYSIS

Figure 1 illustrates what is known as a base-biased transistor amplifier. This is a very simple biasing scheme. As you can see, establishing quiescent currents and voltages requires only two resistors.

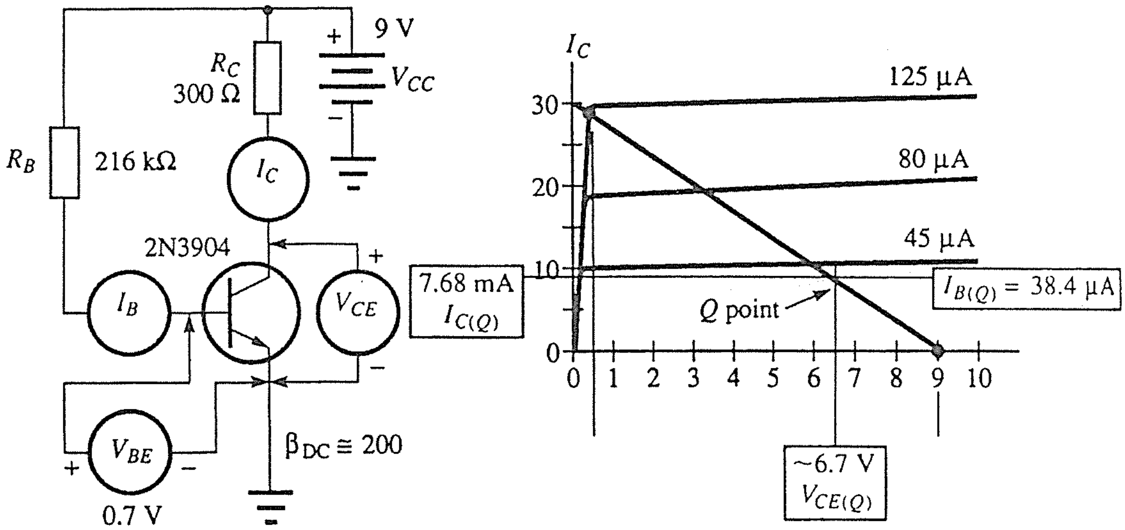


Figure 1 Base-bias circuit analysis.

The theory of operation is very straightforward. The collector current is determined by the amount of base current and the beta (β_{DC}, h_{FE}) of the transistor. The size of the base resistor establishes the amount of base current needed to establish the desired amount of collector current.

When analysing a base-biased circuit, you **always start with the base circuit.** The goal is to determine the quiescent collector current and collector-emitter voltage. Thus, for analysis, start on the base side and work toward the collector side.

[1] Extract from "Exploring Electronic Devices" by Mark Hazen, Saunders College Publishing, 1991

First, calculate the base current. Ohm's Law is used here.

$$I_{B(Q)} = (V_{CC} - 0.7\ V)/\ R_B$$

Note that the base-emitter voltage, estimated to be about 0.7 V for silicon transistors, must be subtracted from the source voltage to obtain the actual voltage across the base resistor. In Figure 1, the base current is found to be 38.4 μA ($I_{B(Q)}$ = (9 V - 0.7 V)/216 kΩ - 38.4 μA).

Next, in order to calculate the collector current, the beta of the transistor must be known. Recall that the collector current is the product of the base current and beta. The transistor in the circuit of Figure 5-1 has a beta of approximately 200. Remember, beta depends on transistor design, operating temperature, and amount of collector current. If the beta is in fact 200, the collector current will be 7.68 mA (200 x 38.4 μA = 7.68 mA).

Once the collector current is known, the collector-emitter voltage can be determined. In this case, the voltage across the transistor ($V_{CE(Q)}$) is the difference between the source voltage (V_{CC}) and the collector-resistor voltage (V_{RC}).

$$V_{CE(Q)} = V_{CC} - V_{RC} = V_{CC} - (I_{C(Q)} \times R_C)$$

For the circuit of Figure 1,

$$V_{CE(Q)} = 9\ V - (7.68\ mA \times 300\ \Omega) = 6.7\ V$$

Finally, a load line can be drawn to visualise the quiescent operating conditions. Recall that the load line is drawn on a graph (family of collector curves) that shows the relationship between base current, collector current, and collector-emitter voltage. The line itself is drawn between saturation ($V_{CE} = 0$, $I_{C(sat)} = V_{CC}/R_C$) and cutoff ($I_C = 0$, $V_{CE(cutoff)} = V_{CC}$). The quiescent collector current and collector-emitter voltage are crossplotted to designate the Q point on the load line. Later you will see the significance of knowing the position of the Q point. For now, consider the analysis shown in Example 1.

EXAMPLE 1

Analyse the circuit of Figure 2 to determine quiescent values of base current, collector current, and collector-emitter voltage. Draw the DC load line and plot the Q point.

DC Load Line

$I_{C(sat)} = V_{CC}/R_C = 10\ V/430\ \Omega = 23.3\ mA$, where $V_{CE(sat)} = 0\ V$.

$V_{CE(cutoff)} = V_{CC} = 10\ V$, where $I_C = 0\ A$.

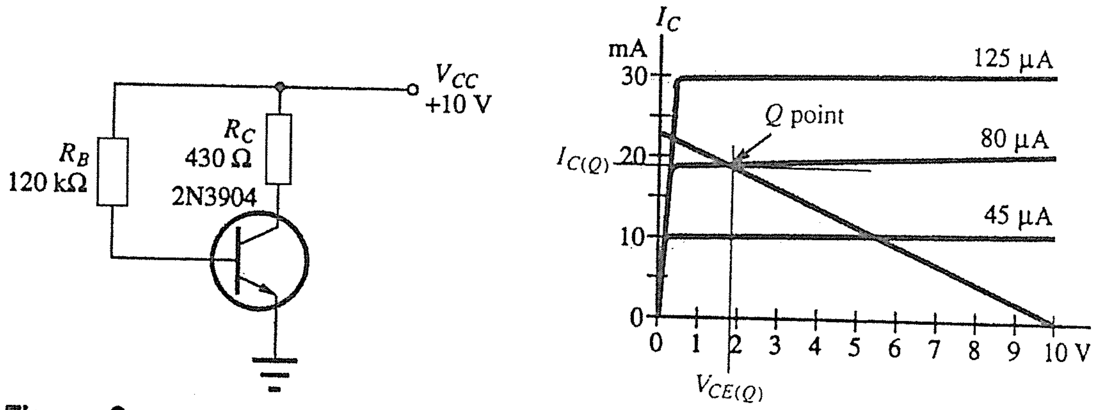


Figure 2

Quiescent Values

$I_{B(Q)} = (V_{CC} - 0.7\ V)/R_B = (10\ V - 0.7\ V)/120\ k\Omega = 77.5\ \mu A$. From the graph we can estimate $I_{C(Q)} \cong 19\ mA$, where $I_{B(Q)} = 77.5\ \mu A$. If $I_{C(Q)} = 19\ mA$, then $V_{RC(Q)} = 19\ mA \times 430\ \Omega = 8.17\ V$.

$$V_{CE(Q)} = V_{CC} - V_{RC(Q)} = 10\ V - 8.17\ V = 1.83\ V$$

$$\beta_{DC} = I_C/I_B = 19\ mA/77.5\ \mu A = 245$$

BASE-BIAS TEMPERATURE STABILITY

At this point you realise that in a base-bias design the quiescent voltage and currents are strongly dependent on the transistor's β_{DC}. Recall how beta changes with temperature. As the transistor operates, it warms from internal power dissipation and ambient (surrounding) temperature change. Naturally, the transistor's beta increases with temperature, which causes the quiescent collector current to increase for a given base current.

In many cases, the increasing collector current causes a further increase in beta, which causes a further increase in collector current. A snowball effect takes place. This is why the base-bias design is very poor, and for many applications unusable. Not only is the design unstable, the circuit cannot be reproduced reliably using other transistors of the same type. Transistors of the same type have a range of beta. The actual beta of the transistor may be anywhere within a 3:1 or 4:1 range. For the 2N3904 transistor, the beta could be anywhere between 100 and 300. As you can see, manufacturers stay away from the base-bias design for good reasons-poor stability and poor reproducibility.

COLLECTOR-FEEDBACK-BIAS ANALYSIS

The amplifier design shown in Figure 3 employs collector feedback. In this case, the bias voltage **is obtained from the collector voltage**. Changes in collector voltage are fed back to the base circuit through the base resistor, offering some improvement in bias-point stability. Like base bias. this design requires only two resistors.

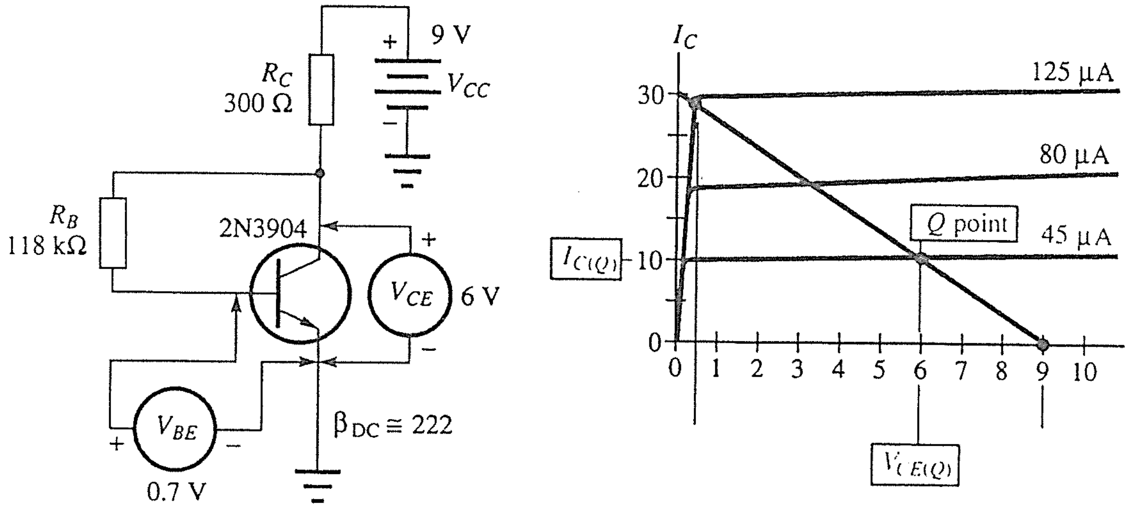


Figure 3 Common-emitter, collector-feedback circuit analysis.

The analysis of a collector-feedback stage begins by knowing the value of the collector-emitter voltage. The collector current is calculated using Ohm's Law to determine the collector-resistor current.

$$I_{C(Q)} = (V_{CC} - V_{CE(Q)}/R_C$$

For the circuit of Figure 3, $V_{CE(Q)}$ is known to be 6 V. Therefore, the quiescent collector current is (9 V - 6 V)/300 Ω = 10 mA.

The base current is calculated in either of two ways. Since the base current still depends on β_{DC}, $I_{B(Q)} = I_{C(Q)}/\beta_{DC}$. Also, the base current can be calculated using Ohm's Law to determine I_{RB}, which is $I_{B(Q)}$.

$$I_{B(Q)} = (V_{CE} - 0.7\ V)/R_B$$

Notice in Figure 3 that the base current is found to be 45 μA using either method (if β_{DC} = 222, then $I_{B(Q)}$ = 10 mA/222 ≅ 45 μA).

The load line can be drawn and the quiescent collector current and collector-emitter voltage can be crossplotted to identify the Q point. Note that the Q point for Figure 3 is not at midpoint. This is not necessarily a problem. as you will understand later. For now, consider Example 2.

EXAMPLE 2

Determine $I_{C(Q)}$ and $I_{B(Q)}$ for the collector-feedback amplifier of Figure 4.

$I_{C(Q)} = (V_{CC} - V_{CE(Q)})/R_C$

$= (12V - 5V)/1k\Omega = 7$ mA

$I_{B(Q)} = (V_{CE} - 0.7\ V)/R_B$

$= (5V - 0.7V)/100\ k\Omega$

$= 43\ \mu A$

$\beta_{DC} = h_{FE} = I_C/I_B$

$= 7\ mA/43\ \mu A$

$= 163$

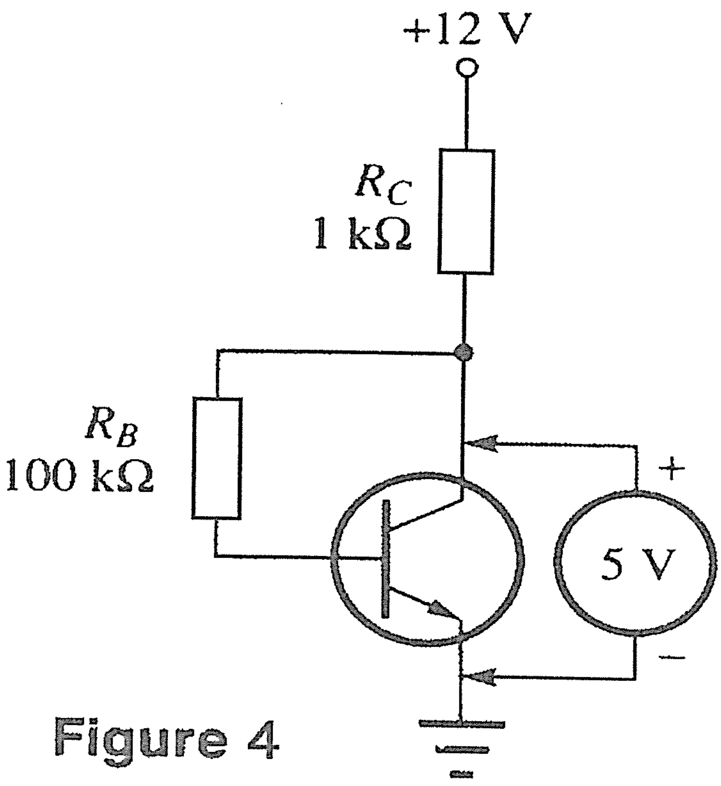


Figure 4

COLLECTOR-FEEDBACK-BIAS TEMPERATURE STABILITY

The idea behind using collector feedback is to obtain better temperature stability than that which is obtained from base bias. In theory, if the collector current begins to increase as a result of increasing temperature and beta, the collector-emitter voltage will decrease.

This is because the increased current causes V_{RC} to increase, leaving less voltage for the transistor ($V_{CE} = V_{CC} - V_{RC}$). The decrease in V_{CE} causes the voltage across R_B, to decrease, which causes I_B to decrease. The decrease in base current is supposed to reduce the collector current, returning it to the normal quiescent value. This feedback loop is supposed to keep the collector current at the quiescent value.

Does it work? Somewhat, but not as well as you might think. Let's derive a new formula that shows the effect of beta on collector current. We'll use Kirchhoff's Voltage Law and form a loop equation for the base loop. This will include V_{RC}, V_{RB}, V_{BE}, and V_{CC}.

$$V_{RC} + V_{RB} + V_{BE} - V_{CC} = 0$$

$$(I_C \times R_C) + (I_B \times R_B) + V_{BE} - V_{CC} = 0$$

Since $I_B = I_C/\beta_{DC}$, we can make the following substitution:

$$(I_C \times R_C) + (I_C \times R_B/\beta_{DC}) + V_{BE} - V_{CC} = 0$$

Solving for I_C:

$$I_C \times [R_C + (R_B/\beta_{DC})] + V_{BE} - V_{CC} = 0$$

$$I_C \times [R_C + (R_B/\beta_{DC})] = V_{CC} - V_{BE}$$

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + \left(R_B / \beta_{DC}\right)}$$

From this formula, we see beta's influence on the collector current. In Figure 4, if beta is 163, the collector current is about 7mA. If beta increases to 200, the collector current increases to approximately 7.53 mA:

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + \left(R_B / \beta_{DC}\right)} = \frac{12\,V - 0.7\,V}{1k\Omega + \left(100k\Omega / 200\right)} = \frac{11.3V}{1k5\Omega} = 7.53mA$$

This increase in current causes the collector-emitter voltage to decrease to 4.46 V (12 V - V_{RC} = 12 V - 7.53 V). This change in Q point may or may not be significant. The point is, the Q point is not rock solid in this design, though it is an improvement over base bias.

VOLTAGE-DIVIDER-BIAS ANALYSIS

Voltage-divider bias is the most common means of transistor biasing. As shown in Figure 5, it requires four resistors instead of just two. This increases the cost per amplifier stage, which is a concern in manufacturing, but the benefits of stability and reproducibility far outweigh the cost.

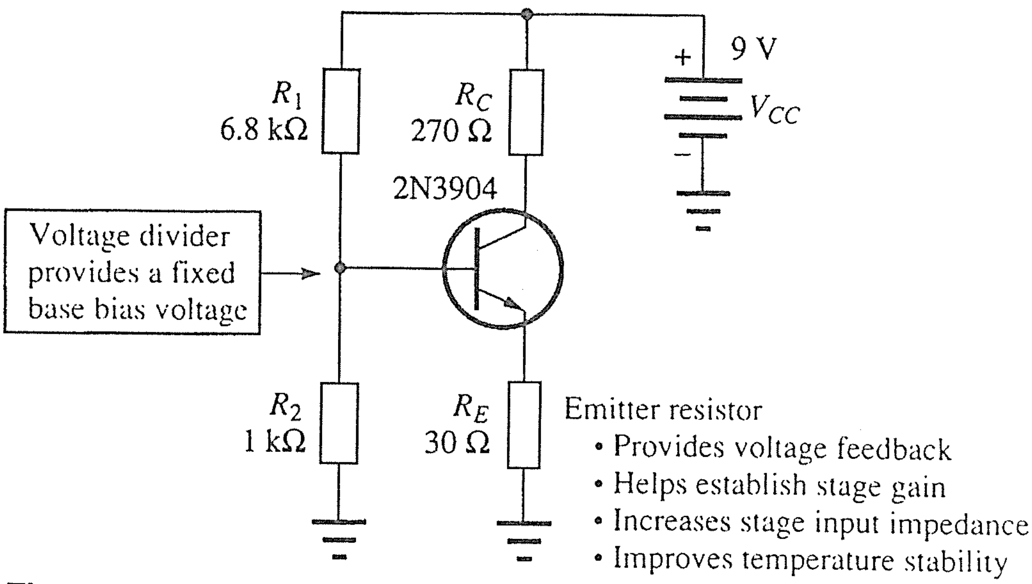


Figure 5 Voltage-divider biasing.

The basic idea behind voltage-divider bias is that a voltage divider provides a fixed bias voltage to the base of the transistor. This fixed base voltage ($V_B = V_{R2}$) then determines the voltage across the emitter resistor ($V_E = V_{RE} = V_B$ - 0.7 V). This emitter voltage then determines the emitter and collector current.

Voltage-divider bias includes an emitter resistor that did not appear in the designs previously discussed. The emitter resistor serves several important functions. It provides some voltage feedback to the base-emitter junction. If the collector current (emitter current) does attempt to increase, due to temperature effects. the emitter-resistor voltage must also increase ($\uparrow V_{RE} = \uparrow I_e \times R_E$). Since the voltage divider provides a fixed base voltage, the increase in emitter voltage reduces V_{BE}, causing I_B to decrease and I_C to remain near the designed Q point ($\leftrightarrow V_B = \downarrow V_{BE} + \uparrow V_{RE}$). Also, the emitter resistor helps determine the gain, or amplification factor, for the transistor stage and increases the input impedance at the base. We will discuss stage gain and input impedance later.

There are six basic steps to voltage-divider bias circuit analysis. This procedure is important since it helps you thoroughly understand the circuit's theory of operation, which in turn enables you to successfully troubleshoot the amplifier. In troubleshooting, you compare predicted (calculated) values with measured values. Let us examine these six analysis steps and apply them to Figure 6.

Voltage-Divider Bias Analysis Steps

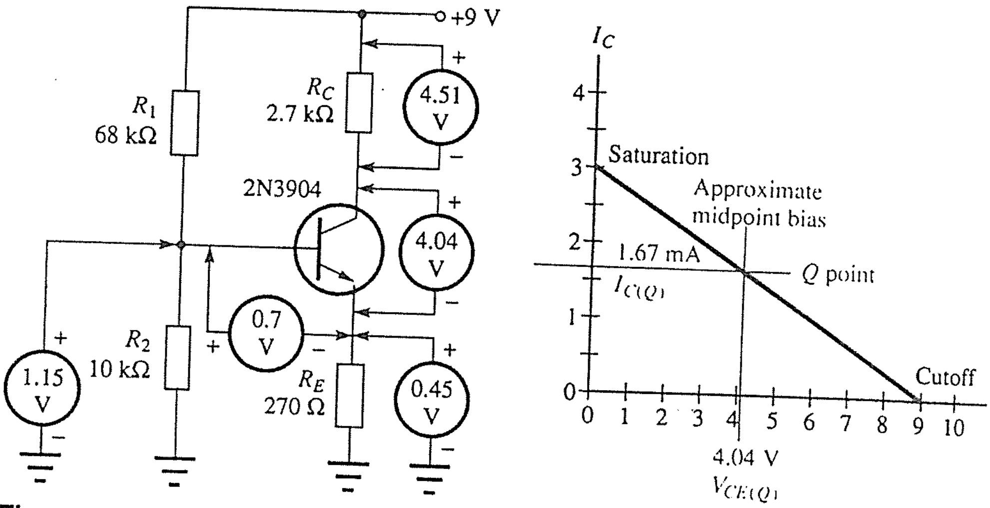


Figure 6 Voltage-divider bias circuit analysis.

1. Establish the load line using $R_C + R_E$ to determine the saturation collector current.

   $I_{C(sat)} \cong V_{CC}/(R_C + R_E) = 9 \text{ V}/(2700\ \Omega + 270\ \Omega) \cong 3 \text{ mA}$

   $V_{CE(cutoff)} = V_{CC} = 9 \text{ V}$

2. Start at the voltage divider and calculate the base voltage.

   $V_B \cong V_{R2} \cong V_{CC} \times [R_2/(R_1 + R_2)]$ *

   $V_B \cong 9 \text{ V} \times [10 \text{ k}\Omega/(68 \text{ k}\Omega + 10 \text{ k}\Omega)] = 1.15 \text{ V}$

   * This formula is an approximation because the base has some loading effect on V_{R2}. In other words, we ignore I_B here.

3. Next, calculate the emitter voltage ($V_E = V_{RE}$). According to Kirchhoff's Voltage Law,

   $V_E \cong V_{RE} = V_B - V_{BE} \cong V_B - 0.7 \text{ V}$

   where $V_B = V_{R2}$

   $V_E \cong 1.15 \text{ V} - 0.7 \text{ V} = 0.45 \text{ V}$

4. Now, calculate the collector current using Ohm's Law.

   $I_C \cong I_E = V_{RE}/R_E$

   $I_C \cong 0.45 \text{ V}/270\ \Omega = 1.67 \text{ mA}$

5. Calculate V_{RC} using Ohm's Law, where $V_{RC} = I_C \times R_C$.

   $V_{RC} = 1.67 \text{ mA} \times 2.7 \text{ k}\Omega = 4.51 \text{ V}$

6. Determine the collector-emitter voltage according to Kirchhoff's Voltage Law.

   $V_{CE(Q)} = V_{CC} - V_{RC} - V_{RE}$

   $V_{CE(Q)} = 9 \text{ V} - 4.51 \text{ V} - 0.45 \text{ V} = 4.04 \text{ V}$

Finally, if desired, crossplot the quiescent collector current and collector-emitter voltage on the load line to identify the Q point.

Carefully study Example 3.

EXAMPLE 3

Analyse the voltage-divider-biased amplifier of Figure 7.

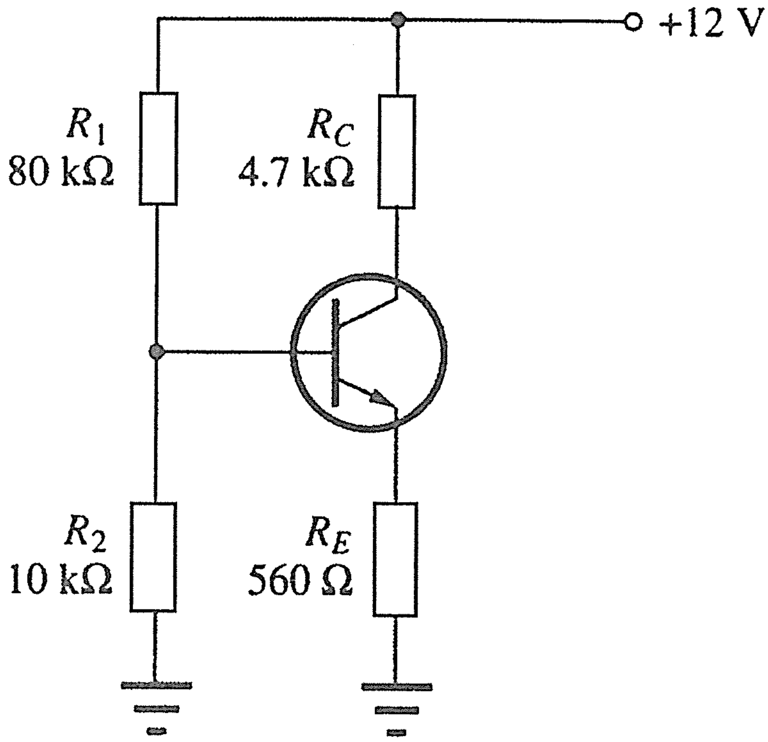


Figure 7

$V_B = V_{CC} \times [R2/(R1 + R2)]$

$= 12\text{ V} \times [10\text{k}\Omega/(80\text{k}\Omega + 10\text{k}\Omega)]$

$= 12\text{ V} \times 10\text{ k}\Omega/90\text{ k}\Omega$

$= 12\text{ V} \times 0.111 = \underline{1.33\text{ V}}$

$V_E = V_{RE} \cong V_B - 0.7\text{ V}$

$= 1.33\text{ V} - 0.7\text{ V} = \underline{0.63\text{ V}}$

$I_{C(Q)} = I_{E(Q)} = V_{RE}/R_E$

$= 0.63\text{ V}/560\ \Omega = \underline{1.13\text{ mA}}$

$V_{RC} = I_{C(Q)} \times R_C$

$= 1.13\text{ mA} \times 4.7\text{ k}\Omega = \underline{5.31\text{ V}}$

$V_{CE(Q)} = V_{CC} - V_{RC} - V_{RE}$

$= 12\text{V} - 5.31\text{V} - 0.63\text{V} = \underline{6.06\text{V}}$

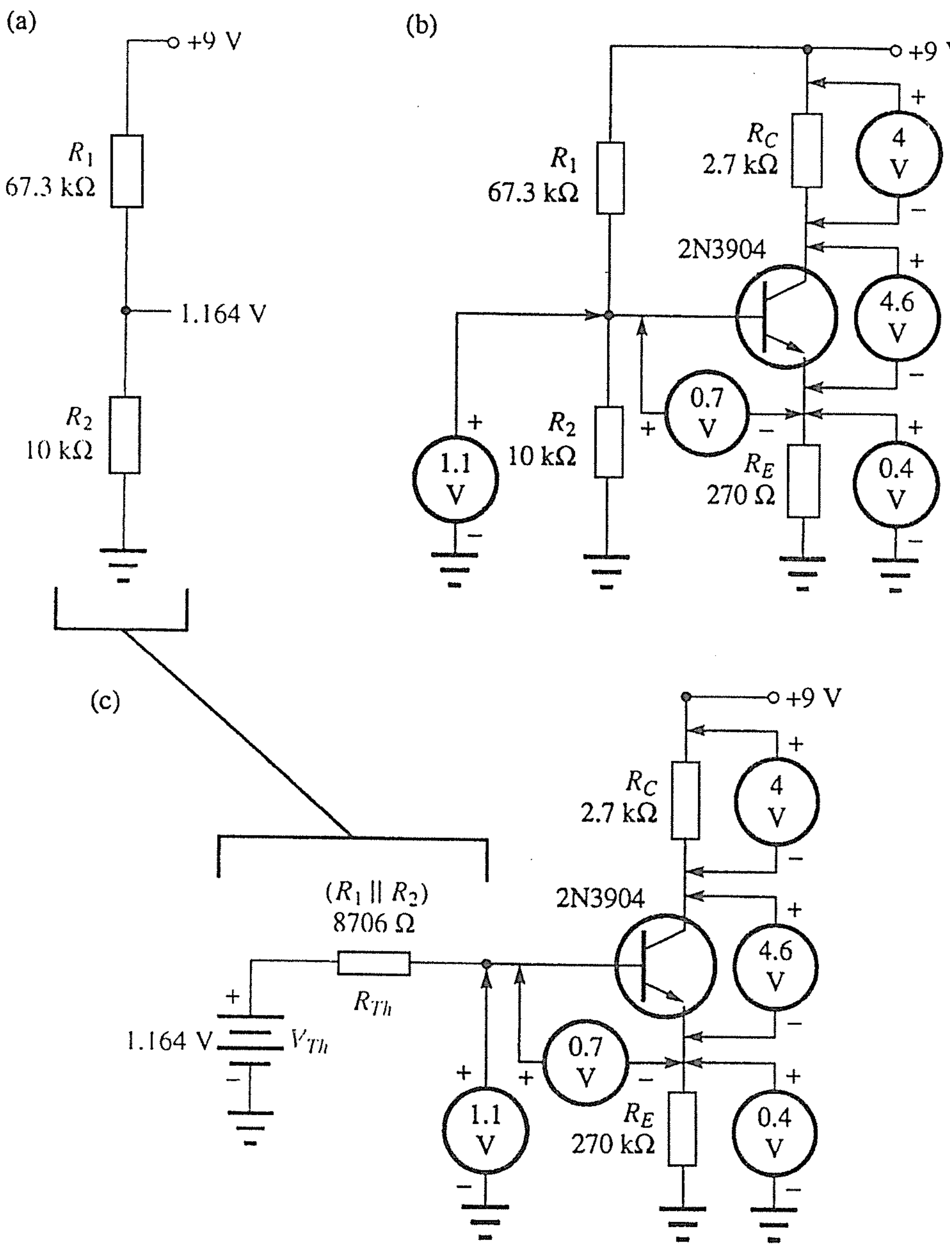
$P_{D(Q)} = I_{C(Q)} \times V_{CE(Q)}$

$= 1.13\text{ mA} \times 6.06\text{ V} = \underline{6.85\text{ mW}}$

VOLTAGE-DIVIDER BIAS TEMPERATURE STABILITY

Temperature and β_{DC}

The temperature stability of the voltage-divider design is not significantly affected by changes in beta as long as the Thevenized resistance of the voltage divider is very low. This is insured by making sure the voltage divider current is at *least 10* times the base current.



$\beta_{DC} = 200$

$I_B \cong I_E/\beta_{DC} = 1.48\ \text{mA}/200 = 7.4\ \mu\text{A}$

$I_E = 0.4\ \text{V}/270\Omega = 1.48\ \text{mA}$

Kirchoff's Voltage Law

$$(R_{Th} \cdot I_B) + V_{BE} + V_E - V_{Th} = 0$$
$$(8706\ \Omega \cdot 7.4\ \mu\text{A}) + 0.7\ \text{V} + 0.4\ \text{V} - 1.164\ \text{V} = 0$$
$$0.064\ \text{V} + 0.7\ \text{V} + 0.4\ \text{V} - 1.164\ \text{V} = 0$$

Figure 8 The Thevenized voltage divider.

As shown in Figure 8, we must Thevenize[2] the voltage divider to form a base-circuit loop. From this, we can use Kirchhoff's Voltage Law to derive a formula that shows the relationship between beta and collector current. We should be able to show that beta has very little effect on collector current. thus making the amplifier very stable over a wide temperature range.

The base loop equation from Figure 8 is as follows:

$$(R_{Th} \times I_B) + V_{BE} + V_E - V_{Th} = 0$$

since $I_C \cong I_E$ and $I_B = I_C/\beta_{DC}$, we obtain the following by substitution:

$$(R_{Th} \times I_C/\beta_{DC}) + V_{BE} + (I_C \times R_E) - V_{Th} = 0$$

$$(I_C \times R_{Th}/\beta_{DC}) + (I_C \times R_E) = V_{Th} - V_{BE}$$

$$I_C \times [(R_{Th}/\beta_{DC}) + R_E] = V_{Th} - V_{BE}$$

therefore,

$$I_C = \frac{V_{Th} - V_{BE}}{(R_{Th}/\beta_{DC}) + R_E}$$

As you can see from this formula, beta has little effect on the collector current and the amplifier's temperature stability as long as R_{Th} is low. Applying this formula to Figure 8, we see that if beta is 200, the collector current is 1.48 mA [(1.164 V - 0.7 V)/[(8.706 Ω/200) + 270 Ω] = 1.48 mA].

If beta increases to 250, the collector current increases to 1.52 mA, which represents no significant change [(1.164 V - 0.7 V)/[(8.706 Ω/250) + 270Ω] = 1.52 mA]. Also, if the transistor is replaced with another 2N3904, or a comparable transistor, the Q point will not change significantly, even if the beta of the new transistor differs greatly from that of the old one.

This formula emphasises the importance of R_{Th} being low. That means voltage-divider resistors R_1 and R_2 must be relatively low in value to insure that changes in β_{DC} with temperature are insignificant. That is why the design rule of thumb proposed is where $I_{R2} \geq 10I_B$. This ensures that the values of R_1 and R_2 will be low enough to provide good temperature stability.

Temperature and VBE

As you have seen, the transistor's β_{DC} is directly related to the transistor's temperature. But that's not the total picture. Associated with an increase in β_{DC} and temperature is a *decrease* in base-emitter barrier potential. V_{BE} is nominally thought of as being 0.7V. As temperature increases, V_{BE} will drop slightly, depending on the amount of increase in temperature. Example 4 illustrates the results of an increase in temperature in a poorly biased amplifier.

[2] *Thevenize*: to apply Thevenin's theorem to reduce a multiloop circuit to an equivalent single loop circuit of source voltage, internal resistance and load resistance. See p. 182 "Fundamentals of DC & AC Circuits" by M Hazen, Saunders College Publishing, 1990.

EXAMPLE 4

Calculate IC(Q) and VCE(Q) for Figure 5-13 when the transistor's β_{DC} is 180. Calculate these parameters again for a β_{DC} of 220 — an increase in β_{DC} due to an increase in temperature. Assume V_{BE} is 0.7 V when β_{DC} is 180 and 0.67 V when β_{DC} is 220.

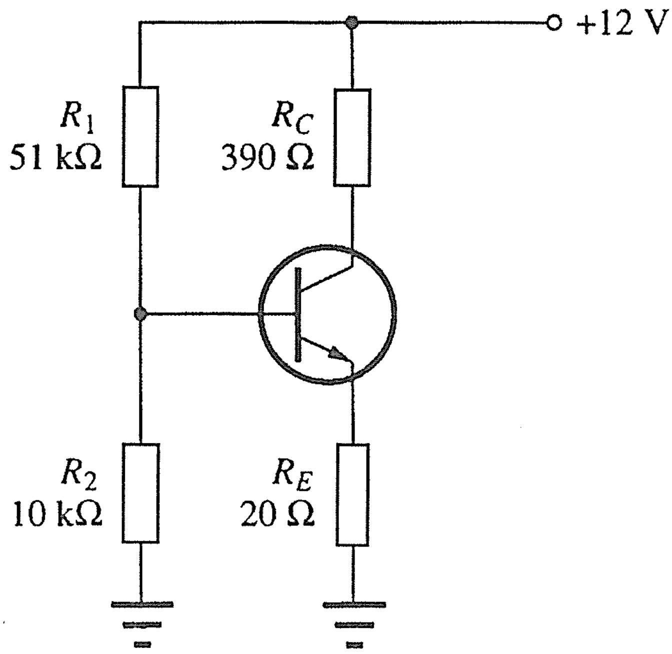


Figure 9

R_{Th} = 51 kΩ||10 kΩ = <u>8.36 kΩ</u>, V_{Th} = 12V x 10kΩ/61 kΩ = <u>1.97V</u>

$\beta_{DC} = h_{FE} = 180$

$$I_C = \frac{V_{Th} - V_{BE}}{(R_{Th}/\beta_{DC}) + R_E} = \frac{1.97V - 0.7V}{(8.36k\Omega/180) + 20\Omega} = \frac{1.27}{46.4\Omega + 20\Omega}$$

= <u>19.1 mA</u>

$V_{CE(Q)} = V_{CC} - V_{RC} - V_{RE}$

= 12 V - (19.1 mA x 390 Ω) - (19.1 mA x 20 Ω)

= 12 V - 7.45 V - 0.38 V = <u>4.17 V</u>

$\beta_{DC} = h_{FE} = 220$

$$I_C = \frac{V_{Th} - V_{BE}}{(R_{Th}/\beta_{DC}) + R_E} = \frac{1.97V - 0.67V}{(8.36k\Omega/220) + 20\Omega} = \frac{1.3}{38\Omega + 20\Omega}$$

= <u>22.4 mA</u>

$V_{CE(Q)} = V_{CC} - V_{RC} - V_{RE}$

= 12 V - (22.4 mA x 390 Ω) - (22.4 mA x 20 Ω)

= 12 V - 8.74 V - 0.45 V = <u>2.81 V</u>

Design Precautions

The changes in Q point due to an increase in temperature illustrated in Example 4 are obviously significant. What design precautions are necessary to avoid this?

First, make sure that R_{Th}/β_{DC} is less than R_E. This is accomplished by making sure R_{Th} is low by using relatively low values for R_1 and R_2. Again, this is ensured by making $I_{R2} \geq 10I_{B(Q)}$. More suitable values for R_1 and R_2 in Figure 9 would be R_1 = 5.1 kΩ and R_2 = 1 kΩ, if it is desired that $V_{CE(Q)}$ be between 3 and 4 V over a wide temperature range.

Second, V_{Th} should be greater than approximately 1.5 V_{BE} so slight de-creases in V_{BE}, as temperature increases, will have little effect. The slight decrease in V_{BE} shown in Example 9 really has little effect because V_{Th} is relatively large compared to V_{BE}.

V_{Th} is made relatively large by insuring that V_{RE} is not too small. V_{RE} should be greater than approximately 0.35 V whenever possible. This is accomplished by making R_E large enough to provide a voltage drop greater than 0.35 V for the desired quiescent collector current. The larger R_E and V_{RE} are, the better the temperature stability.

EMITTER-BIAS ANALYSIS

Though not as common, emitter bias is a close cousin to voltage-divider bias. Shown in Figure 10, ***emitter bias requires a split supply instead of the voltage divider.***

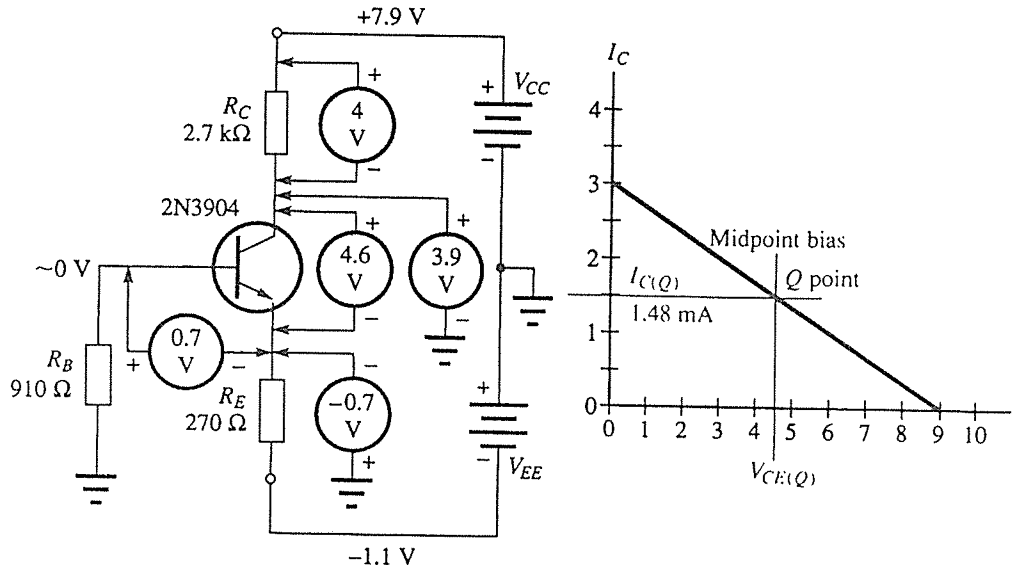


Figure 10 Emitter-bias circuit analysis.

The V_{EE} supply provides the emitter resistor and the base-emitter junction with the needed voltage drops with respect to ground. Notice that the base is close to ground potential (near 0 V). The base resistor is kept small to insure that the base is close to ground potential ($V_B = I_B \times R_B$ = near 0 V). This circuit functions the same and has nearly the same Q point as the circuit of Figure 6. The following analysis steps are applied to the circuit of Figure 10.

Emitter-Bias Analysis Steps

1. Draw the load line. Notice here that $V_{CE(cutoff)}$ is the sum of the two supplies since they are series-aiding. Also, $I_{C(sat)}$ is determined using the sum of the two supply voltages.

   $I_{C(sat)} = (V_{CC} + V_{EE})/(R_C + R_E)$

   $I_{C(sat)} = (7.9\text{ V} + 1.1\text{ V})/(2.7\text{ k}\Omega + 270\ \Omega) \cong \underline{3\text{ mA}}$

   $V_{CE(cutoff)} = V_{CC} + V_{EE}$

   $V_{CE(cutoff)} = 7.9\text{ V} + 1.1\text{ V} = \underline{9\text{ V}}$

2. Calculate the emitter current using Ohm's Law, where

   $V_{RE} = V_E - V_{BE} \cong V_{EE} - 0.7\text{ V}$

   $I_C \cong I_E = V_{RE}/R_E$

   $I_C = 0.4\text{ V}/270\ \Omega = \underline{1.48\text{ mA}}$

3. Next, calculate the voltage across the collector resistor using Ohm's Law ($V_{RC} = I_C \times R_C$).

   $V_{RC} = 1.48\text{ mA} \times 2.7\text{ k}\Omega = \underline{4\text{ V}}$

4. Finally, calculate $V_{CE(Q)}$.

   $V_{CE(Q)} = V_{CC} + V_{EE} - V_{RC} - V_{RE} = V_C - V_E$

   $V_{CE(Q)} = 7.9\text{ V} + 1.1\text{ V} - 4\text{ V} - 0.4\text{ V} = \underline{4.6\text{ V}}$

Notice that the collector of the transistor is at +3.9 V with respect to ground and the emitter of the transistor is at -0.7 V with respect to ground. The total voltage drop from collector to emitter is the total difference of potential [+3.9 - (-0.7) = 4.6 V]. Notice also that V_E and V_{RE} are not equal as they were in the voltage-divider design. Here, V_E is = 0.7 V and V_{RE} is 0.4 V. Now, take time to carefully study Example 5.

EXAMPLE 5

Determine $I_{C(sat)}$, $V_{CE(cutoff)}$, $I_{C(Q)}$, and $V_{CE(Q)}$ for Figure 11.

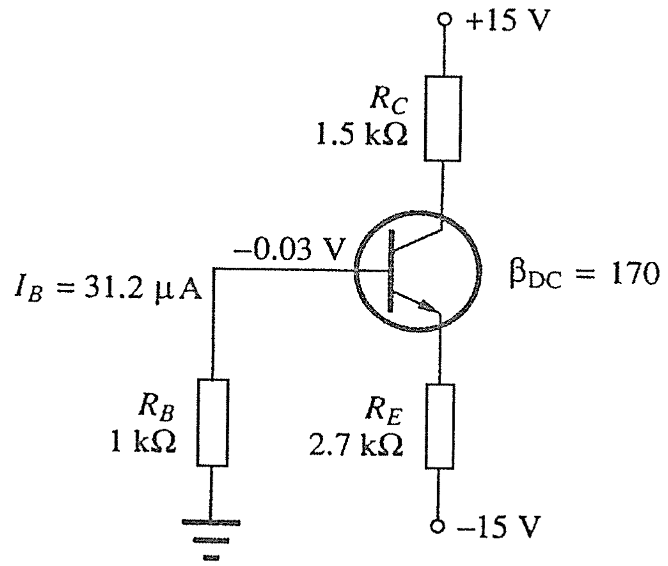


Figure 11

$V_{CE(cutoff)} = +15\text{ V} - (-15\text{ V}) = \underline{30\text{ V}}$

$I_{C(sat)} = 30\text{ V}/4.2\text{ k}\Omega = \underline{7.14\text{ mA}}$

$I_{C(Q)} \cong I_{E(Q)} = V_{RE}/R_E = (15\text{ V} - 0.7\text{ V})/2.7\text{ k}\Omega = \underline{5.30\text{ mA}}$

$V_{CE(Q)} = V_C - V_E = (15\text{ V} - (5.3\text{ mA} \times 1.5\text{ k}\Omega) - (-0.7\text{ V}) = \underline{7.75\text{ V}}$

Notice also that $I_{B(Q)} = I_{C(Q)}/\beta_{DC} = 5.30\text{ mA}/170 = 31.2\ \mu\text{A}$ and $V_B = I_{B(Q)} \times R_B = 31.2\ \mu\text{A} \times 1\text{ k}\Omega = 0.031\text{ V} \cong \underline{0\text{ V}}$.

Emitter-Bias Temperature Stability

The temperature stability and circuit reproducibility in the emitter-bias design are both as good or better than the voltage-divider design. Again, the minimal effects of changes in beta can be seen in a formula derived from Kirchhoff's Voltage Law.

$$(R_B \times I_B) + V_{BE} + V_{RE} - V_{EE} = 0$$

Since $I_C \cong I_E$ and $I_B = I_C/\beta_{DC}$, we obtain the following by substitution.

$$(R_B \times I_C/\beta_{DC}) + V_{BE} + (I_C \times R_E) - V_{EE} = 0$$

$$(I_C \times R_B/\beta_{DC}) + (I_C \times R_E) = V_{EE} - V_{BE}$$

$$I_C \times [(R_B/\beta_{DC}) + R_E] = V_{EE} - V_{BE}$$

Therefore,

$$I_C = \frac{V_{EE} - V_{BE}}{(R_B/\beta_{DC}) + R_E}$$

As you can see from this last formula, beta has virtually no effect on collector current because R_B/β_{DC} is very small compared to R_E. Also notice that changes in V_{BE} with temperature have virtually no effect on the collector current, because V_{EE} *is* normally very large compared to V_{BE}. Therefore, emitter bias is a very temperature-stable design.

TEMPERATURE-STABILITY FACTORS

BETA

We have already discussed the fact that beta changes with temperature and how it can continue to increase as transistor current and temperature increase. In power transistors this can be a severe problem as the collector current and temperature run away. As temperature increases, current increases, which further increases temperature. If precautions are not taken, collector current and device temperature can drive each other to destruction. This is often referred to as *thermal runaway.*

The threat of thermal runaway is minimised with good biasing techniques such as voltage-divider or emitter bias and proper heat sinking. Naturally, we will pursue this further in covering power amplifiers.

VARIATIONS IN SOURCE POLARITY AND GROUND

In this section, we illustrate different ways to apply DC source voltage to transistor amplifiers. Figure 12 illustrates some of the possible variations.

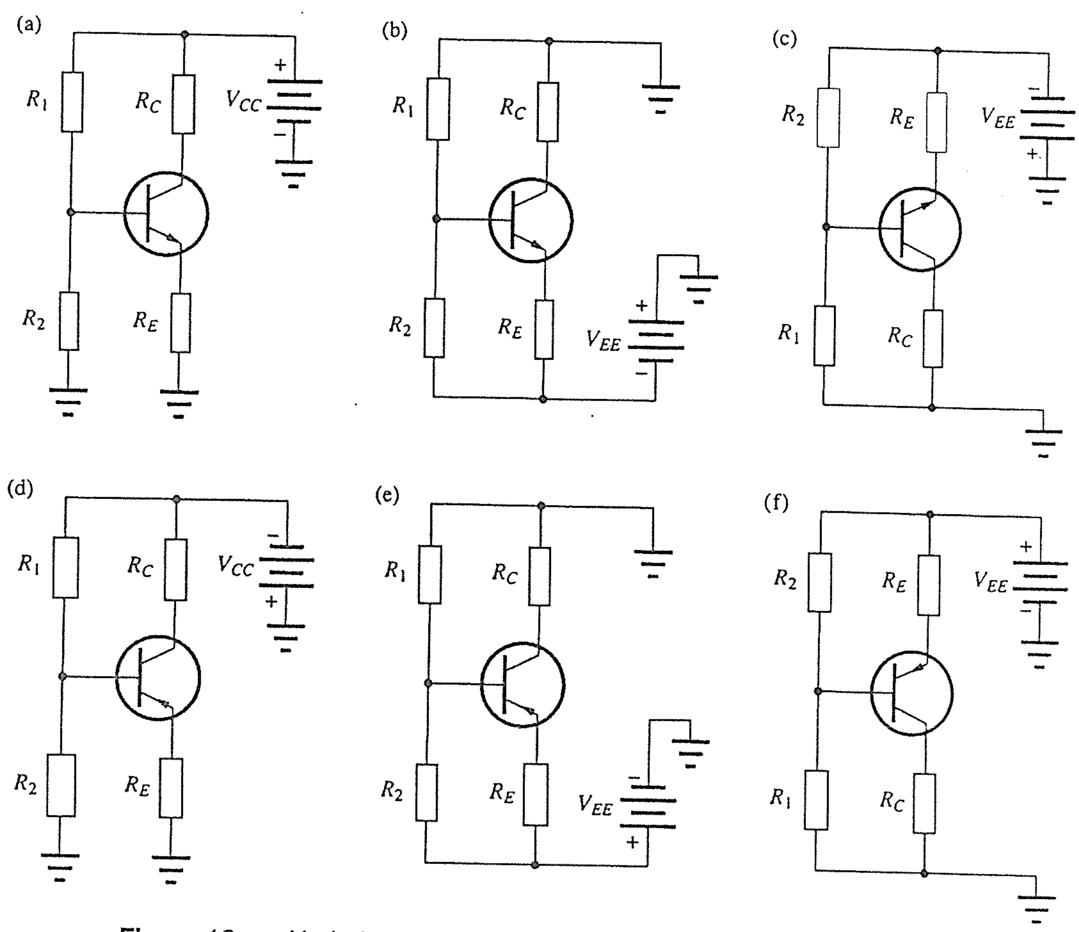


Figure 12 Variations in source polarity and ground for NPN and PNP circuits.

Figures 12a and 12d are standard NPN and PNP configurations. Realise that all circuit calculations are the same for NPN and PNP transistors. Note that the proper polarity for each transistor type is maintained.

Figures 12c and 12f are the same as Figures 12b and 12e respectively. The diagrams are simply inverted.

Figures 12d, e, and f are complements of Figures 12a, b, and c. That is, the circuits function the same but are opposite in voltage polarities, current directions, and transistor type. Later, you will see how the NPN and PNP transistors can be placed in the same amplifier circuit to increase the efficiency of the circuit. It is said that they ***complement*** one another, forming a ***complementary pair***. For example, the 2N3904 and 2N3906 are complementary, having very similar operating characteristics and ratings.

It might be a good idea to take time now to go back and review the various biasing techniques. You should be able to recognise many similarities in the way collector current and base current are determined in each design. Ohm's Law is used over and over again in many different ways. Also, make sure you understand the advantages and disadvantages of the various biasing schemes.